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A METHOD OF ESTIMATING PRECIPITATION CHARACTERISTICS

[0001] The present invention relates to a method of estimating precipitation characteristics and in particular precipitation rate for solid precipitation.

[0002] It is known from the state of the art that the characteristics of a radar image can be used to estimate rainfall characteristics. In particular, European Patent EP 1 049 944 describes a technique for estimating rainfall using a radar. In that patent, provision is made for the following steps:

- using that dual-polarized radar to measure the differential phase shift (Φdp) and the apparent reflectivity Z in at least one of the H (horizontal) or V (vertical) polarizations and over a given range [ro, ri] of path radii relative to said radar;
- determining an estimate of the value No* representative of the size distribution of the rain drops, on the basis of the differential phase shift difference over the range ro to ri, and on the basis of an integral of a function of the apparent reflectivity Z, over the range [ro, ri]; and
- deducing the value of the precipitation rate at a point on the basis of No* and of the apparent reflectivity at said point.

[0003] A method of estimating rainfall is also known from PCT Patent WO03007016 which describes a method of estimating a precipitation rate by means of a dual-polarized radar, that method being characterized by the following steps:

- using that dual-polarized radar to measure the differential phase shift Φdp and the attenuated reflectivity Z in at least one of the H or V polarizations and over a given range [r1, r0] of path radii r relative to said radar;

- determining an estimate of the value K(r0) of the specific attenuation at r0 on the basis of the profile of the attenuated reflectivity measured in this way, and on the basis of the differential phase shift difference over the range r0 to r1; determining an estimate K(r) of the specific attenuation at r as a function of the attenuation K(r0) determined in this way and of the attenuated reflectivity profile Z(r); and determining the precipitation rate R(r) once K(r) is known.

[0004] Those various solutions make it possible to characterize liquid precipitation and to estimate precisely rainfall rate (in millimeters per hour (mm/h), but they do not make it possible to estimate the characteristics of solid precipitation such as snow.

[0005] An object of the invention is to provide a novel method that remedies that drawback.

[0006] To this end, and in its most general acceptation, the invention provides a method of estimating precipitation characteristics and in particular precipitation rate for solid precipitation, said method comprising an acquisition and processing step consisting in acquiring a radar image including at least a vertical plane of a precipitation zone, and in processing a vertical profile so as to deliver digital signals representative of reflectivity in the vertical direction h, said method being characterized in that it further comprises an integration step consisting in integrating said signals representative of reflectivity so as to deliver a signal representative of the profile in the vertical plane of a the mean particle diameter weighted by the mass of each particle, and a determination step consisting in determining the concentration of the solid particles on the basis of the signals computed in the preceding steps.

[0007] Preferably, the integration step consists in determining the variable Z(h) of the radar observable in mm^6/m^3 as a function of the altitude h on the basis of said radar image, and in determining said mean diameter Dm(h) of the particles by resolving the following equation:

$$\frac{fD_m}{fh} = -0.25 k_{eff} a D_m^{b-5} 10^{-18} Z + \left(\frac{1}{6} \frac{1}{Z} \frac{fZ}{fh} \right) D_m \qquad (2)$$

where:

Z is the radar observable to be inverted in $mm^6 m^{-3}$;

D_m is in meters (m);

a and *b* are coefficients specific to particles of the "aggregate" type; for example, the coefficient *a* is equal to 35184 and the coefficient *b* is equal to 3.16;

k_{eff} is the coefficient of effectiveness of the aggregation process to be adjusted, said coefficient k_{eff} being equal to 0.3.

[0008] Integration of (2) requires an integration boundary condition. Advantageously, said integration boundary condition is determined so that the value $D_m(h)$ at the top of the cloud corresponds to the predetermined value for the total number of particles at the top of the cloud.

[0009] In an advantageous implementation, the profile of the total number of particles $n_t(h)$ is determined by the following equation:

$$n_T(h) = x.Z(h)/D_m(h)^6$$

where x is equal to $25.4\ 10^{-18}$.

[0010] In another implementation, the meteorological parameter $N_0(h)$ is determined by the following equation:

$$N_0(h) = y.Z(h)/D_m(h)^7$$

where *y* is equal to $102\ 10^{-18}$.

[0011] In a third implementation, the meteorological parameter corresponding to the profile of the ice water content *IWC(h)* (in g/m^3] is determined by the following equation:

$$IWC(h) = wZ(h)/D_m(h)^3$$

where *w* is equal to $1.25\ 10^{-12}$.

[0012] In a fourth implementation, the meteorological parameter corresponding to the profile of the solid precipitation rate R(h) (mm/h equivalent melted) is determined by the following equation:

$$R(h)=r.Z(h)/D_m(h)^{2.35}$$

where r is equal to 4.698 10^{-10}.

[0013] The invention will be better understood on reading the following description, given with reference to a non-limiting implementation.

- Figure 1 shows an example of a vertical profile of Z to be inverted (in this example, the isotherm 0°C is at ground level);
- Figure 2 shows the profile of Dm resulting from Z being inverted by the aggregation model compared with the conventional estimator;
- Figure 3 shows the profiles of N0 and of nT resulting from Z being inverted by the aggregation model compared with the conventional hypothesis and observations;
- Figure 4 shows the vertical profile of Z to be inverted;
- Figure 5 shows the profile of Dm resulting from Z being inverted by the aggregation model compared with the conventional estimator;
- Figure 6 shows the profiles of N0 and nT resulting from the Z being inverted by the aggregation model compared with the conventional hypothesis and observations;
- Figure 7 shows the profile of R resulting from Z being inverted by the aggregation model compared with the conventional estimator;
- Figure 8 shows the sensitivity of the retrieval of the equivalent precipitation rate (mm/h) to the particle density law $\rho(D) \propto D\text{-}\gamma$; and

- Figure 9 shows the sensitivity of the retrieval of the vertical Doppler velocity to the particle density law $\rho(D) \propto D^{-\gamma}$.

[0014] The method applies essentially to stratiform precipitation. It considers that the ice-forming nuclei are activated only at highly negative temperatures, i.e. at the top of the cloud. The ice crystals formed at high altitude settle and grow as they fall, either by sublimation of the ambient saturating water vapor, or by collection and freezing of supermelted cloud water droplets, or else by random aggregation of their collisions with other ice crystals. Of the three growth processes, only aggregation changes the ice particle concentration. The characterization method is based essentially on a simplified description of the aggregation mechanism. The invention is based on a class of "profiler" methods in that it inverts the vertical profile of reflectivity measured in the ice, so as to extract therefrom the vertical profile of the solid precipitation rate.

[0015] The steps of the inversion method are as follows:

1 – Particle size distribution expressed in "equivalent melted diameter" is assumed to be exponential, i.e.:

$$N(D)=N_0\exp(-4D/D_m) \qquad (1)$$

where $N(D)$ is the concentration of particles per cubic meter (m^3) and per diameter range, and N_0 and D_m are the two parameters that characterize distribution.

2 – The top h_{max} and the base h_{min} of the layer of solid precipitation are determined;

a. h_{max} is the maximum altitude of the measured reflectivity profile $Z(h)$.

b. h_{min} is either the altitude of the isotherm 0°C if the ground-level temperature is positive, or it is ground level if the ground-level temperature is negative.

3 – The profile of the parameter Dm(h) in the range h_{max} to h_{min} is then determined by resolving the following differential equation:

$$\frac{fD_m}{fh} = -0.25 k_{eff} a D_m^{b-5} 10^{-18} Z + \left(\frac{1}{6} \frac{1}{Z} \frac{fZ}{fh} \right) D_m \qquad (2)$$

where:

- Z is the radar observable to be inverted in mm^6m^{-3};

- D_m is in meters (m);

- a and b are coefficients specific to particles of the "aggregate" type, equal respectively to 35184 and to 3.16 on the basis of the observations of Locatelli and Hobbs (1974);

- k_{eff} is the coefficient of effectiveness of the aggregation process to be adjusted (the value $k_{eff} = 0.3$ seems correct).

4 – The integration of (2) takes place from the top, where the boundary condition is expressed by fixing the total number of particles n_T (or the number of ice-forming nuclei activated at the top of the cloud). It is possible to take $n_T(h_{max}) = 10^6\ m^{-3}$, which makes it possible to express the boundary condition $D_m(h_{max})$ as:

$$Dm(H_{max})=25.4\ 10^{-18}(Z(h_{max}/n_T(h_{max}))^{1/6} \qquad (3)$$

5 – Once the profile $D_m(h)$ from h_{max} to h_{min} has been determined, the profiles of the other parameters of interest are computed by the following expressions:

a. Profile of N_0: $N_0(h)=102.10^{-12}Z(h)/D_m(h)^7$

b. Profile of the total number of particles $n_T(h)$ [in m^{-3}]: $N_T(h)=102.10^{-12}Z(h)$ $/D_m(h)^6$

c. Profile of the ice water content IWC(h) (in g/m^3]:

$IWC(h)=1.25.10^{-12}Z(h)/D_m(h)3$

d. Profile of the solid precipitation rate R(h) (mm/h equivalent melted). By using the terminal fall velocity determined by Locatelli and Hobbs for aggregates: [v_T=107.6 $D^{0.65}$ (D in m)], $R(h)$ is expressed by:

$$R(h)=4.698.10^{-10}Z(h)/D_m(h)^{2.35}$$

[0016] The following description relates to another version of the method of processing for determining the precipitation rate.

[0017] For rainfall, the algorithm used is the ZPHI algorithm which is the subject of French Patent Documents FR9800714 and FR0109206.

[0018] For solid precipitation, the novel algorithm that has just been developed is the subject of the following description.

[0019] This algorithm for estimating the precipitation rate for solid precipitation belongs to the class of "profiler" algorithms in that it inverts the vertical profile of reflectivity measured in the ice, so as to extract therefrom the vertical profile of the solid precipitation rate.

[0020] The algorithm applies essentially to stratiform precipitation. It considers that the ice-forming nuclei are activated only at highly negative temperatures, i.e. at the top of the cloud. The ice crystals formed at high altitude settle and grow as they fall, either by sublimation of the ambient saturating water vapor, or by collection and freezing of supermelted cloud water droplets, or else by random aggregation of their collisions with other ice crystals. Of the three growth processes, only aggregation changes the ice particle concentration. The algorithm is based essentially on a simplified description of the aggregation mechanism. The steps of the inversion method are as follows:

Particle size distribution expressed in "equivalent melted diameter" is assumed to be exponential, i.e.:

$$N(D)=N_0\exp(-4D/D_m) \qquad (1)$$

where D is the equivalent melted diameter of the ice particle;

N(D) is the concentration of particles per m^3 and per diameter range; and

N_0 and D_m are the two parameters that characterize distribution.

The top h_{max} and the base h_{min} of the layer of solid precipitation are determined;

h_{max} is the maximum altitude of the measured reflectivity profile Z(h).

h_{min} is either the altitude of the isotherm 0°C if the ground-level temperature is positive, or it is ground level if the ground-level temperature is negative.

[0021] The profile of the parameter $D_m(h)$ in the range h_{max} to h_{min} is then determined by resolving the following differential equation, whose solution can be determined analytically:

$$\frac{\partial D_m}{\partial h} = -24\,\frac{4^d \quad k_{eff} J(b,d) a}{\Gamma(4+d) \;\; á(â-1)}\; Z D_m^{\,b-(â-2)} + \frac{1 \quad \partial Z}{(â-1)Z \; \partial h}\; D_m \qquad (2)$$

where:

$$J(b,d) = \int_0^{\infty} \exp(-4x)x^b \int_0^{x} \left[x^d - x'^d \right] \exp(-4x')dx'dx$$

describes the collision frequency;

Z is the radar observable to be inverted in $mm^6 m^{-3}$;

D_m is in m;

- *a, b, c,* and *d* are coefficients dependent on the density law F(D) for ice particles, which law is assumed to vary at $D^{-\gamma}$ (where γ can take values in the range 0.25 to 1.1 depending on the type of particles). These coefficients are drawn from Mitchell's Theory (Journal of Atmospheric Sciences, 53, 12, 1996) for representing the following power laws:

$v_t(D) = cD^d$ (where v_t is the terminal fall velocity of the particle of equivalent melted diameter D):

$A = aD^b$ (where A is the effective cross-section of the particle of equivalent melted diameter D);

With coefficients depending on frequency and on a function of (D), representing by a power law the relationship between reflectivity (measured parameter), the concentration of the particles, and their mean equivalent diameter:

$Z = áN_0D_m^{\,d}$

k_{eff} is the coefficient of effectiveness of the aggregation process to be adjusted (the value $k_{eff} = 0.3$ seems correct immediately above the isotherm 0°C).

[0022] The integration of (2) takes place from the top, where the boundary condition is expressed by fixing the total number of particles n_T (or the number of ice-forming nuclei activated at the top of the cloud). It is possible to take $n_T\,(h_{max}) = 10^6$ m^{-3}, which makes it possible to express the boundary condition $D_m(h_{max})$ as:

$$D_m(h_{max}) = \left[\frac{1}{4án_T(h_{max})} Z(h_{max})\right]^{\frac{1}{â-1}} \quad (3)$$

[0023] Once the profile $D_m(h)$ from h_{max} to h_{min} has been determined, the profiles of the other parameters of interest are computed by the following expressions:

Profile of N_0:

$$N_0(h) = \frac{Z(h)}{áD_m(h)^{â}}$$

Profile of the total number of particles $n_T(h)$ [in m^{-3}]: $n_T(h)=0.25N_0(h)D_m(h)$

Profile of the ice water content IWC(h) (in g/m^3]:

$$IWC(h)=(1.2272)10^4 N_0(h)D_m(h)^4$$

Profile of the solid precipitation rate R(h) (mm/h equivalent melted):

$$R(h)=(1.885)10^6\, c \quad \frac{\Gamma(4+d)}{4^{(4+d)}} N_0(h)D_m(h)^{(4+d)}$$

Vertical profile of the Doppler velocity $V_D(h)$ (in meters per second (m/s)), given by a power law dependent on density _(D):

$$V_D(h)=pD_m(h)^q$$

[0024] Because of the dependency of the coefficients relative to the density law *F(D)*, the retrieval of the precipitation rate depends critically on the parameter γ, as shown by Figure 7. The density law thus constitutes a key parameter.

[0025] By operating in vertical firing, it is possible to measure the Doppler velocity $V_D(h)$, and to compare it with $V_D(h)$ computed by the algorithm. The Doppler velocity profile is discriminating, as shown by Figure 8. By successive adjustments, it is thus possible to determine the parameter $\gamma$of the law F(D) for which consistency between $V_D(h)$ as computed and $V_D(h)$ as measured is achieved. Figure 4 shows an example of a profile inverted by the algorithm (in this example, the isotherm 0°C is at ground level). Figure 5 shows the curves resulting from application of the aggregation model and of the conventional model, making it possible for the profile of D_M resulting from the inversion of Z by the aggregation model to be compared with the conventional estimator.

[0026] Figure 6 shows the curves of the profiles as a function of altitude (m) above the isotherm 0°C. It enables the profiles of N_0 and n_T resulting from Z being inverted by the aggregation model to be compared with the conventional hypothesis and observations. Figure 7 shows the profile of R resulting from Z being inverted by the aggregation model compared with the

conventional estimator. Figure 8 shows the sensitivity of the retrieval of the equivalent participation rate (mm/h) to the particle density law $\rho(D) \propto D^{-\gamma}$. Figure 9 shows the sensitivity of the retrieval of the vertical Doppler velocity to the particle density law $\rho(D) \propto D^{-\gamma}$.